10 PERFORMANCE OF FUNCTION

The FGS is expected to perform its intended function throughout the airplane's normal flight envelope. There are considerations for the FGS when operating at the limits of its performance capabilities and when operating under significant environmental conditions. The following sections provide acceptable means of compliance criteria and interpretive material for these considerations.

Where system tolerances have a significant effect on autopilot authority limits, consideration should be given to the effect on autopilot performance. Factors to be considered include but are not limited to tolerances of: servo authority, servo clutch setting, "cam-out" settings, control friction, and sensor tolerances.

10.1 Normal Performance

The FGS should provide guidance or control, as appropriate, for the intended function of the active mode(s) in a safe and predictable manner within the airplane's normal flight envelope.

The FGS should be designed to operate in all airplane configurations for its intended use within the airplane's normal flight envelope to provide acceptable performance for the following types of environmental conditions::

- Winds (light and moderate)
- Wind gradients (light and moderate)

  NOTE: In the context of this AC, "wind gradient" is considered a variation in wind velocity as a function of altitude, position, or time.

- Gusts (light and moderate)
- Turbulence (light and moderate)
- Icing (trace, light, moderate)

  NOTE: Representative levels of the environmental effects should be established consistent with the airplane's intended operation.

Any performance characteristics that are operationally significant or operationally limiting should be identified with an appropriate statement or limitation in the Airplane Flight Manual (AFM).

The FGS should perform its intended function during routine airplane configuration or power changes, including the operation of secondary flight controls.

Evaluation of FGS performance for compliance should be based on the minimum level of performance needed for its intended functions. Subjective judgment may be applied to account for experience acquired from similar equipment and levels that have been established as operationally acceptable by the end-user.

There are certain operations that dictate a prescribed level of performance. When the FGS is intended for operations that require specific levels of performance, the use of FGS should be shown to meet those specific levels of performance (e.g., Low Visibility Operations – Category II and III operations, Reduced Vertical Separation Minimums (RVSM), Required Navigation Performance (RNP)).

The FGS performance of intended functions should at least be equivalent to that expected of a pilot for a similar task. The Flight Test Guide (AC 25-7A) and the Autopilot, Flight Director and Autothrust Systems SAE ARP 5366 may prove useful for establishing the general behavior of the FGS. When

integrated with navigation sensors or flight management systems, the FGS should satisfy the flight technical error tolerances expected for the use of those systems in performing their intended functions.

The autopilot should provide smooth and accurate control without perceptible sustained nuisance oscillation.

The flight director, in each available display presentation (e.g., single cue, cross-pointer, flight path director) should provide smooth and accurate guidance and be appropriately damped, so as to achieve satisfactory control task performance without pilot compensation or excessive workload.

The autothrust function should provide smooth and accurate control of thrust without significant or sustained oscillatory power changes or excessive overshoot of the required power setting.

The automatic pitch trim function should operate at a rate sufficient to mitigate excessive control surface deflections or limitations of control authority without introducing adverse interactions with automatic control of the aircraft. Automatic roll and yaw trim functions, if installed, should operate without introducing adverse interactions with automatic control of the aircraft.

10.2 Performance in Rare Normal Conditions

The FGS will encounter a wide range of conditions in normal operations, some of which may be infrequent, but levy a greater than average demand on the FGS capabilities. Certain environmental conditions, as listed below, are prime examples. FGS performance during such rare normal conditions should be assessed. Such conditions may degrade FGS performance, but must be safe for FGS operation. The relative infrequency of such conditions may also be a factor in the flight crew's ability to detect and mitigate, in a timely manner, any limited capability of the FGS to cope with them. The FGS should be limited from operating in environmental conditions in which it cannot be safely operated.

This does not mean that the FGS must be disengaged when rare normal conditions, which may degrade its performance or capability, are encountered. Actually, the FGS may significantly help the flight crew during such conditions. However, the design should address the potential for the FGS to mask a condition from the flight crew or to otherwise delay appropriate flight crew action. See Section 9.3, Flight Guidance Alerting for discussion of alerting under such conditions.

Operations in rare normal environmental conditions may result in automatic or pilot-initiated autopilot disengagement close to the limit of autopilot authority. Autopilot disengagement in rare normal conditions should meet the safety criteria for autopilot disengagement found in Section 8.1 and the criteria for flight guidance alerting in Section 9.3.

For rare normal conditions, the FGS should provide guidance or control, as appropriate for the intended function of the active mode(s), in a safe and predictable manner, both within the normal flight envelope and for momentary excursions outside the normal flight envelope.

The following rare normal environmental conditions should be considered in the design of the FGS:

- Significant winds
- Significant wind gradients
- Windshear (e.g., microburst)

  NOTE: For the purpose of this AC, "windshear" is considered a wind gradient of such a magnitude that it may cause damage to the aircraft. Airplanes intended to meet § 121.358 for windshear warning and guidance need flight director windshear guidance. The FGS may also provide suitable autopilot control during windshear. Refer to Advisory Circulars AC 25-12 and AC 120-41 for windshear guidance system requirements.

- Large gusts (lateral, longitudinal, and vertical dimensions)
- Severe and greater turbulence (check AIM language)
- Severe or unusual types/effects of icing (e.g., airfoil contamination)

10.2.1 Icing Considerations

The FGS typically will be designed to provide acceptable performance in all standard airplane configurations. Operating an airplane in icing conditions can have significant implications on the aerodynamic characteristics of the airplane (e.g., ice accretion on wings, tail, and engines) and, consequently, on FGS performance. Ice accretion may be slow, rapid, symmetric, or asymmetric. During autopilot operation, the flight crew may not be aware of the gradual onset of icing conditions or the affect that the accumulation of ice is having on the handling qualities of the airplane.

Means should be provided to alert the flight crew as described in Section 9.3.

The implication of icing conditions on speed protection should be assessed. If the threshold of the stall warning system is adjusted due to icing conditions, appropriate adjustments should also be made to the FGS low speed protection threshold.

10.3 Performance in Non-Normal Conditions

The FGS will occasionally be operating when the airplane transitions outside of the normal flight envelope of the airplane, when other airplane systems experience failure conditions (e.g., inoperative engine, loss of hydraulics) or when the airplane experiences certain extraordinary conditions such as significant fuel imbalance, non-standard flap/slat or ferry configurations. Under such circumstances, the FGS characteristics and flight crew interaction with the FGS should be shown to be safe.

10.4 Speed Protection (25.1329(h))

The requirement for speed protection is based on the premise that reliance on flight crew attentiveness to airspeed indications, alone, during FGS operation is not adequate to avoid unacceptable speed excursions outside the speed range of the normal flight envelope. Many existing FGS systems have no provisions to avoid speed excursions outside the normal flight envelope. Some FGS systems will remain engaged until the aircraft slows to stall conditions and also to speeds well above V_{MO}/M_{MO}.

Standard stall warning and high-speed alerts are not always timely enough for the flight crew to intervene to prevent unacceptable speed excursions during FGS operation. The intent of the rule is for the FGS to provide a speed protection function for all operating modes, such that the airspeed can be safely maintained within an acceptable margin of the speed range of the normal flight envelope.

For compliance with the intent of the rule, other systems, such as the primary Flight Control System or the FMS when in a VNAV mode, may be used to provide equivalent speed protection functionality.

If the FGS is providing speed protection function, the following are acceptable means to comply with this rule:

- The FGS may detect the speed protection condition, alert the flight crew and provide speed protection control or guidance.
- The FGS may detect the speed protection condition, alert the flight crew and then disengage the FGS.

- The FGS may detect the speed protection condition, alert the flight crew, and remain engaged in the active mode without providing speed protection control or guidance.

  NOTE: If compliance with this requirement is based on use of alerting alone, the alerts should be shown to be appropriate and timely to ensure flight crew awareness and enable the pilot to keep the airplane within an acceptable margin from the speed range of the normal flight envelope. See Section 9.3.1 for additional discussion of speed protection alerting.

The design should consider how and when the speed protection is provided for combinations of autopilot, flight directors, and autothrust operation.

Care should be taken to set appropriate values for transitioning into and out of speed protection that the flight crew does not consider a nuisance.

The speed protection function should integrate pitch and thrust control. Consideration should be given to automatically activating the autothrust function when speed protection is invoked. If an autothrust function is either not provided or is unavailable, speed protection should be provided through pitch control alone.

The role and interaction of autothrust with elements of the FMS, the primary flight control system, and the propulsion system, as applicable, should be accounted for in the design for speed protection.

Consideration should be given to the effects of an engine inoperative condition on the performance of speed protection.

10.4.1 Low Speed Protection

When the FGS is engaged in any modes (with the possible exception of approach as discussed in Section 10.4.1.1) for which the available thrust is insufficient to maintain a safe operating speed, the low speed protection function should be invoked to avoid unsafe speed excursions.

Activation of speed protection should take into account the phase of flight, factors such as turbulence and gusty wind conditions, and be compatible with the speed schedules. The low speed protection function should activate at a suitable margin to stall warning consistent with values that will not result in nuisance alerts. Consider the operational speeds, as specified in the Airplane Flight Manual (AFM), for all-engine and engine-inoperative cases during the following phases of flight:

- Takeoff.

- During departure, climb, cruise, descent and terminal area operations airplanes are normally operated at or above the minimum maneuvering speed for the given flap configuration.

  NOTE: For high altitude operations, it may be desirable to incorporate low speed protection at the appropriate engine out drift-down speed schedule if the FGS (or other integrated sensors/systems) can determine that the cause of the thrust deficiency is due to an engine failure.

- Approach.

  NOTE: A low speed alert and a transition to the speed protection mode at approximately $1.2V_S$, or an equivalent speed defined in terms of V_{SR}, for the landing flap configuration has been found to be acceptable.

- The transition from approach to go-around and go-around climb.

10.4.1.1 Low Speed Protection during Approach Operations

Speed protection should not interfere with the landing phase of flight.

It is assumed that with autothrust operating normally, the combination of thrust control and pitch control during the approach will be sufficient to maintain speed and desired vertical flight path. In cases where it is not, an alert should be provided in time for the flight crew to take appropriate corrective action.

For approach operations with a defined vertical path (e.g., ILS, MLS, GLS, LNAV/VNAV), if the thrust is insufficient to maintain both the desired flight path and the desired approach speed, there are several ways to meet the intent of low speed protection:

a) The FGS may maintain the defined vertical path as the airplane decelerates below the desired approach speed until the airspeed reaches the low speed protection value. At that time the FGS would provide guidance to maintain the low speed protection value as the airplane departs the defined vertical path. The FGS mode reversion and low speed alert should be activated to ensure pilot awareness.

   NOTE: The pilot is expected to take corrective action to add thrust and return the airplane to the defined vertical path or go-around as necessary.

b) The FGS may maintain the defined vertical path as the airplane decelerates below the desired approach speed to the low speed protection value. The FGS will then provide a low speed alert while remaining in the existing FGS approach mode.

   NOTE: The pilot is expected to take corrective action to add thrust to cause the airplane to accelerate back to the desired approach speed while maintaining the defined vertical path or go-around as necessary.

c) The FGS may maintain the defined vertical path as the airplane decelerates below the desired approach speed until the airspeed reaches the low speed protection value. The FGS will then provide a low speed alert and disengage.

   NOTE: The pilot is expected to take corrective action when alerted to the low speed condition and the disengagement of the autopilot, to add thrust and manually return the airplane to the desired vertical path or go-around as necessary.

The FGS design may use any one or a combination of these ways to provide acceptable low speed protection.

If the speed protection is invoked during approach such that vertical flight path is not protected, the subsequent behavior of the FGS after speed protection should be carefully considered. Activation of low speed protection during the approach, resuming the approach mode and reacquiring the defined vertical path, may be an acceptable response if the activation is sufficiently brief and not accompanied by large speed or path deviations. This is considered consistent with criteria for Category III automatic landing systems, in JAR-AWO 107 and AC 120-28D, Appendix 3, Section 8.1 Automatic Flight Control Systems, which states that it must not be possible to change the flight path of the airplane with the automatic pilot(s) engaged, except by initiating an automatic go-around.

10.4.1.2 Windshear

The interaction between low speed protection and windshear recovery guidance is a special case. Windshear recovery guidance that meets the criteria found in Advisory Circulars AC 25-12 and AC 120-41 provides the necessary low speed protection when it is activated, and is considered to be

acceptable for compliance with §/JAR 25.1329(h). The autopilot must be disengaged when the windshear recovery guidance activates, unless autopilot operation has been shown to be safe in these conditions and provides effective automatic windshear recovery that meets the criteria found in the advisory circulars referenced above.

10.4.2 High Speed Protection

§/JAR 25.1329(h) states that the means must be provided to avoid excursions beyond an acceptable margin from the speed range of the normal flight envelope V_{MO} and M_{MO} mark the upper speed limit of the normal flight envelope. This is not intended to require, or preclude, high speed protection based on airplane configurations (e.g., flaps).

The following factors should be considered in the design of high-speed protection:

1. The duration of airspeed excursions, rate of airspeed change, turbulence, and gust characteristics.

    a) Operations at or near V_{MO}/M_{MO} in routine atmospheric conditions (e.g., light turbulence) are safe. Small, brief excursions above V_{MO}/M_{MO}, by themselves, are not unsafe.

    b) The FGS design should strive to strike a balance between providing adequate speed protection margin and avoiding nuisance activation of high-speed protection.

NOTE: The following factors apply only to designs that provide high-speed protection through FGS control of airspeed.

2. FGS in altitude hold mode:

    a) Climbing to control airspeed is not desirable, because departing an assigned altitude can be disruptive to ATC and potentially hazardous (for example, in RVSM airspace). It is better that the FGS remain in altitude hold mode.

    b) The autothrust function, if operating normally, should effect high-speed protection by limiting its speed reference to the normal speed envelope (i.e., at or below V_{MO}/M_{MO}).

    c) The basic airplane high-speed alert should be sufficient for the pilot to recognize the overspeed condition and take corrective action to reduce thrust as necessary. However, if the airspeed exceeds a margin beyond V_{MO}/M_{MO} (e.g., six knots), the FGS may transition from altitude hold to the overspeed protection mode and depart (climb above) the selected altitude.

3. During climbs and descents:

    a) When the elevator channel of the FGS is not controlling airspeed, the autothrust function (if engaged) should reduce thrust, as needed to prevent sustained airspeed excursions beyond V_{MO}/M_{MO} (e.g., six knots), down to the minimum appropriate value.

    b) When thrust is already the minimum appropriate value, or the autothrust function is not operating, the FGS should begin using the elevator channel, as needed, for high-speed protection.

    c) If conditions are encountered that result in airspeed excursions above V_{MO}/M_{MO}, it is preferable for the FGS to smoothly and positively guide or control the airplane back to within the speed range of the normal flight envelope.